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# ST-segment depression and T-wave inversion: Classification, differential diagnosis, and caveats

## ABSTRACT

Heightened awareness of the characteristic patterns of ST-segment depression and T-wave inversion is paramount to quickly identifying life-threatening disorders. This paper reviews how to distinguish the various causes of these abnormalities.

## KEY POINTS

ST-T abnormalities concordant to the QRS complex suggest ischemia.

Deep T-wave inversion or positive-negative biphasic T waves in the anterior precordial leads reflect severe left anterior descending coronary artery stenosis.

Two particular patterns of ST-segment depression reflect ST-segment elevation myocardial infarction rather than non-ST-segment elevation acute coronary syndrome: ST-segment depression that is reciprocal to a subtle and sometimes overlooked ST-segment elevation, and ST-segment depression that is maximal in leads  $V_1$ – $V_3$ , suggesting true posterior infarction.

T-wave inversion in the anterior precordial leads may be seen in cases of acute pulmonary embolism, while flattened T waves with prominent U waves and ST-segment depression may reflect hypokalemia or digitalis therapy.

DEPRESSION of the ST segment and inversion of the T wave are common electrocardiographic abnormalities. Knowing the various ischemic and nonischemic morphologic features is critical for a timely diagnosis of high-risk myocardial ischemia and electrolyte- or drug-related abnormalities. Moreover, it is important to recognize that true posterior infarction or subtle ST-segment elevation infarction may masquerade as ST-segment depression ischemia, and that pulmonary embolism may masquerade as anterior ischemia. These common electrocardiographic abnormalities are summarized in **TABLE 1**.

## THE ST SEGMENT AND THE T WAVE: A PRIMER

Abnormalities of the ST segment and the T wave represent abnormalities of ventricular repolarization.

The ST segment corresponds to the plateau phase of ventricular repolarization (phase 2 of the action potential), while the T wave corresponds to the phase of rapid ventricular repolarization (phase 3). ST-segment or T-wave changes may be secondary to abnormalities of depolarization, ie, pre-excitation or abnormalities of QRS voltage or duration.

On the other hand, ST-segment and T-wave abnormalities may be unrelated to any QRS abnormality, in which case they are called *primary repolarization abnormalities*. These are caused by ischemia, pericarditis, myocarditis, drugs (digoxin, antiarrhythmic

TABLE 1

**Differential diagnosis of ST-segment depression or T-wave inversion****Secondary repolarization abnormalities**

ST segment and T wave move in the same direction, discordant to QRS

**Ischemic ST-segment or T-wave abnormalities<sup>a</sup>**

ST segment or T wave may be concordant to QRS  
ST segment and T wave may go in opposite directions  
Symmetric and pointed T-wave inversion  
Positive-negative biphasic T wave

**Wellens syndrome**

Symmetric and deeply inverted T waves  
OR

Positive-negative biphasic T wave in leads  $V_2$  and  $V_3$ , occasionally  $V_1$ ,  $V_4$ ,  $V_5$ , and  $V_6$   
PLUS

Isoelectric or minimally elevated (< 1-mm) ST segment  
No precordial Q waves  
Prolonged QT interval  
History of chest pain in the last hours to days  
Pattern present in pain-free state  
Normal or slightly elevated cardiac serum markers

**True posterior STEMI**

Maximal ST-segment depression in  $V_1$ - $V_3$   
ST-segment elevation in  $V_7$ - $V_9$

**ST-segment depression reciprocal to subtle ST-segment elevation**

Subtle ST-segment elevation concomitant to a more marked ST-segment depression in the reciprocal leads

**Pulmonary embolism**

T-wave inversion in the anterior or inferior leads, or both  
ST elevation in the anterior or inferior leads, or both  
Sinus tachycardia, rSR' in  $V_1$ - $V_2$ , right ventricular hypertrophy, rightward QRS axis shift, "P pulmonale"  
Rapid regression of abnormalities on serial tracings favors pulmonary embolism rather than myocardial infarction

**Hypokalemia**

ST-segment depression  
T-wave flattening  
Prominent U wave (with the flattened T wave, may mimic a wide and notched upright T wave)  
Prolonged QTU interval

**Digitalis effect**

Similar to hypokalemia, except that ST-segment depression is typically sagging, T-U wave separation is more distinct, and QT interval is shortened

**Takotsubo cardiomyopathy**

ST-segment elevation in the precordial leads or more diffusely  
Diffuse T-wave inversion  
Prolonged QT interval

**Acute pericarditis**

Diffusely inverted or biphasic T waves  
ST-segment elevation has often resolved at this stage

**Memory inverted T waves**

Appear after pacing, transient left bundle branch block, or transient tachycardia

**Mild rapidly reversible T-wave abnormalities**

T-wave inversion occurs with standing, with hyperventilation, or after a meal

**Persistent juvenile T-wave pattern**

T-wave inversion in  $V_1$ - $V_3$   
Decrements between  $V_1$  and  $V_3$   
Young female (< 40 years old)  
No other electrocardiographic or clinical abnormality

**Global T-wave inversion**

T-wave inversion in most leads except aVR  
T wave sometimes giant (> 10 mm)  
May be seen with ischemia, intracranial processes, hypertrophic cardiomyopathy, cocaine use, pericarditis, myocarditis, Takotsubo cardiomyopathy, pulmonary embolism, advanced atrioventricular block

<sup>a</sup>Any one of these features suggests ischemia. ECG=electrocardiogram; LBBB=left bundle branch block; MI=myocardial infarction; PE=pulmonary embolism; STEMI=ST-segment elevation myocardial infarction

drugs), and electrolyte abnormalities, particularly potassium abnormalities.

ST-segment deviation is usually measured at its junction with the end of the QRS complex, ie, the J point, and is referenced against the TP or PR segment.<sup>1</sup> But some prefer to measure the magnitude of the ST-segment

deviation 40 to 80 ms after the J point, when all myocardial fibers are expected to have reached the same level of membrane potential and to form an isoelectric ST segment; at the very onset of repolarization, small differences in membrane potential may normally be seen and may cause deviation of the J

## ST DEPRESSION, T INVERSION



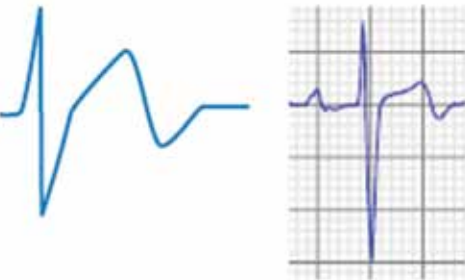
(A) ST-segment depression and asymmetric T-wave inversion secondary to left ventricular hypertrophy (left) and left bundle branch block (right).



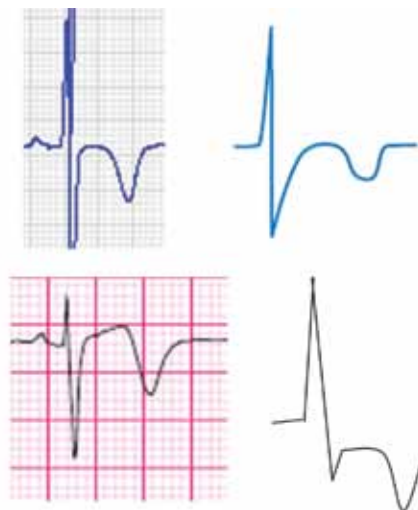
(B) ST-segment depression and T-wave inversion concordant to QRS, suggestive of ischemia.



(C) ST-segment depression with an upright or biphasic negative-positive T wave, suggestive of ischemia.



(D) Positive-negative biphasic T wave with a minimally elevated J point and an angle of 60 to 90 degrees between the initial ascending portion and the descending portion of the T wave (Wellens-type T-wave abnormality, usually seen in precordial leads  $V_1$ - $V_4$ ). This finding is very specific for ischemia.



(E) Symmetric and pointed deep T-wave inversion with an isoelectric or a slightly up-sloping or horizontally depressed ST segment (isoelectric: top two panels; slightly up-sloping: third panel; horizontally depressed: fourth panel); often follows the biphasic T waves seen in 1D by hours to days. As the T-wave changes subsequently regress, the positive-negative biphasic T-waves are again seen before repolarization returns to normal.

**FIGURE 1.** ST-segment and T-wave morphologies in cases of secondary abnormalities (A) and ischemic abnormalities (B–E).

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point and of the early portion of the ST segment.<sup>2</sup>

Although a diagnosis of ST-segment elevation myocardial infarction (STEMI) that mandates emergency reperfusion therapy requires ST-segment elevation greater than 1 mm in at least two contiguous leads,<sup>3</sup> any ST-segment depression or elevation ( $\geq 0.5$  mm, using the usual standard of 1.0 mV = 10 mm) may be abnormal, particularly when the clinical context or the shape of the ST segment suggests ischemia, or when other ischemic signs such as T-wave abnormalities, Q waves, or reciprocal ST-segment changes are concomitantly present. On the other hand, ST-segment depression of up to 0.5 mm in leads V<sub>2</sub> and V<sub>3</sub> and 1 mm in the other leads may be normal.<sup>1</sup>

In adults, the T wave normally is inverted in lead aVR; is upright or inverted in leads aVL, III, and V<sub>1</sub>; and is upright in leads I, II, aVF, and V<sub>2</sub> through V<sub>6</sub>. The T wave is considered inverted when it is deeper than 1 mm; it is considered flat when its peak amplitude is between 1.0 mm and -1.0 mm.<sup>1</sup>

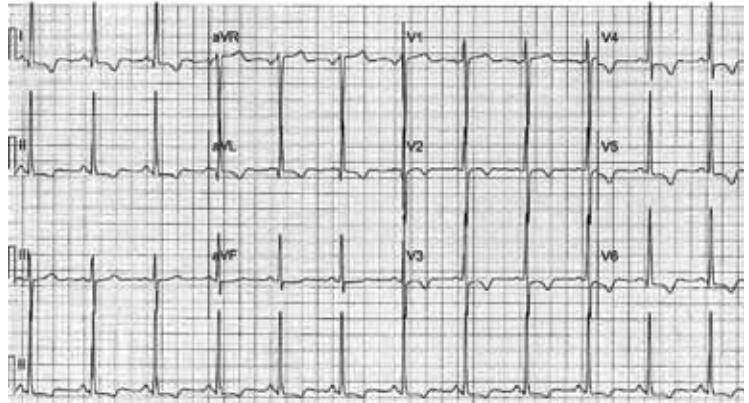
As we will discuss, certain features allow the various causes of ST-segment and T-wave abnormalities to be distinguished from one another.

## ■ SECONDARY ST-SEGMENT AND T-WAVE ABNORMALITIES

In secondary ST-segment or T-wave abnormalities, QRS criteria for left or right ventricular hypertrophy or left or right bundle branch block or pre-excitation are usually present, and the ST segment and T wave have *all* of the following morphologic features (FIGURE 1A):

- The ST segment and T wave are directed opposite to the QRS: this is called *discordance* between the QRS complex and the ST-T abnormalities. In the case of right bundle branch block, the ST and T are directed opposite to the terminal portion of the QRS, ie, the part of the QRS deformed by the conduction abnormality.
- The ST segment and T wave are both abnormal and deviate in the same direction, ie, the ST segment is down-sloping and the T wave is inverted in leads with an upright QRS complex, which gives the ST-T

## Left ventricular hypertrophy



**FIGURE 2.** Example of left ventricular hypertrophy with typical secondary ST-T abnormalities in leads I, II, aVL, V<sub>4</sub>, V<sub>5</sub>, and V<sub>6</sub>. The QRS complex is upright in these leads while the ST segment and T wave are directed in the opposite direction, ie, the QRS and the ST-T complexes are discordant.

complex a “reverse checkmark” asymmetric morphology.

- The ST and T abnormalities are not dynamic, ie, they do not change in the course of several hours to several days.

Thus, in cases of left ventricular hypertrophy or left bundle branch block, since the QRS complex is upright in the left lateral leads I, aVL, V<sub>5</sub>, and V<sub>6</sub>, the ST segment is characteristically depressed and the T wave is inverted in these leads (FIGURE 2). In cases of right ventricular hypertrophy or right bundle branch block, T waves are characteristically inverted in the right precordial leads V<sub>1</sub>, V<sub>2</sub>, and V<sub>3</sub>.

Left bundle branch block is always associated with secondary ST-T abnormalities, the absence of which suggests associated ischemia. Left and right ventricular hypertrophy, on the other hand, are not always associated with ST-T abnormalities, but when these are present, they correlate with more severe hypertrophy or ventricular systolic dysfunction,<sup>4</sup> and have been called *strain pattern*. In addition, while these morphologic features are consistent with secondary abnormalities, they do not rule out ischemia in a patient with angina.

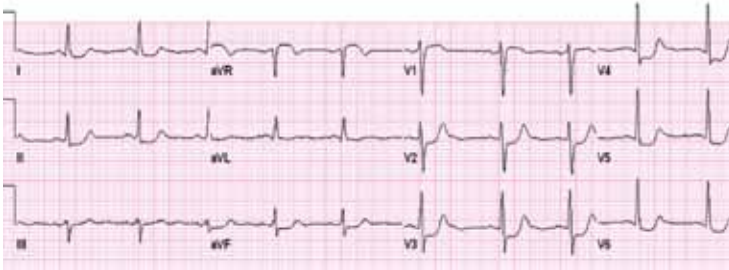
**Some exceptions** to these typical morphologic features:

- Right ventricular hypertrophy and right bundle branch block may be associated

**Any ST-segment depression or elevation  $\geq 0.5$  mm may be abnormal**



**Three-vessel disease**



**FIGURE 3.** Electrocardiogram of a patient with angina at rest and elevated cardiac biomarkers. ST-segment depression in nine leads with elevation in leads aVR and V<sub>1</sub> suggested subendocardial ischemia related to three-vessel or left main coronary artery disease. He had severe three-vessel disease on coronary arteriography.

**Wellens syndrome**



**FIGURE 4A.** Wellens-type biphasic T wave in leads V<sub>2</sub> and V<sub>3</sub> (arrows) and T-wave inversion in leads V<sub>4</sub> and V<sub>5</sub>.



**FIGURE 4B.** Wellens-type deep T-wave inversion in leads V<sub>2</sub> to V<sub>4</sub>. Each patient had a 90% proximal left anterior descending stenosis at coronary arteriography.

with isolated T-wave inversion without ST-segment depression in precordial leads V<sub>1</sub>, V<sub>2</sub>, and V<sub>3</sub>.

- Left ventricular hypertrophy may be associated with symmetric T-wave inversion without ST-segment depression or with a horizontally depressed ST segment. This may be the case in up to one-third of ST-T abnormalities secondary to left ventricular hypertrophy and is seen in hypertrophic cardiomyopathy, particularly the apical variant, in leads V<sub>3</sub> through V<sub>6</sub>.<sup>5</sup>

**ISCHEMIC ST-SEGMENT DEPRESSION, T-WAVE INVERSION, OR BOTH**

ST-segment depression or T-wave inversion is consistent with ischemia if any of the following is true:

- The ST-segment depression or T-wave inversion is directed in the same direction as the QRS complex: this is called *concordance* between the QRS complex and the ST or T abnormality (FIGURE 1B).
- The ST segment is depressed but the T wave is upright (FIGURE 1C).
- The T wave has a positive-negative biphasic pattern (FIGURE 1D).
- The T wave is symmetrically inverted and has a pointed configuration, while the ST segment is not deviated or is upwardly bowed (coved) or horizontally depressed (FIGURE 1E).
- The magnitude of ST-segment depression progresses or regresses on serial tracings, or ST-segment depression progresses to T-wave abnormality during ischemia-free intervals (dynamic ST-segment depression).

Unlike ST-segment elevation, ST-segment depression does not localize ischemia.<sup>6</sup> However, the extent and the magnitude of ST-segment depression correlate with the extent and the severity of ischemia. In fact, ST-segment depression in eight or more leads, combined with ST-segment elevation in leads aVR and V<sub>1</sub> and occurring during ischemic pain, is associated with a 75% predictive accuracy for left main coronary artery or three-vessel disease (FIGURE 3).<sup>7,8</sup> This finding may also be seen in cases of tight proximal stenosis of the left anterior descending coronary artery.<sup>9</sup>

**Wellens syndrome**

Either the positive-negative biphasic T waves of the type shown in FIGURE 1D or the deeply inverted ( $\geq 5$  mm) T waves that often follow them, when occurring in the precordial leads V<sub>2</sub> and V<sub>3</sub>, with or without similar changes in V<sub>1</sub>, V<sub>4</sub>, and V<sub>5</sub>, are nearly pathognomonic of very recent severe ischemia or injury in the distribution of the left anterior descending artery and characterize what is known as *Wellens syndrome* (FIGURE 4).<sup>10-13</sup>

Wellens and his colleagues showed that 75% of patients who developed these T-wave

abnormalities and who were treated medically without angiographic investigation went on to develop extensive anterior wall myocardial infarction within a mean of 8.5 days.<sup>10</sup>

In a later investigation of 1,260 patients presenting with unstable angina, 180 patients (14%) had this characteristic T-wave pattern.<sup>11</sup> All of the latter patients had stenosis of 50% or more in the proximal left anterior descending artery, and 18% had total occlusion of the left anterior descending artery.

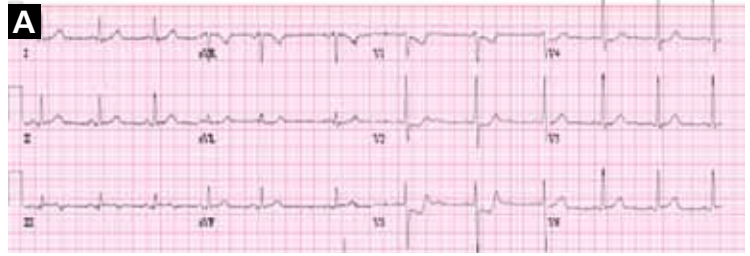
Thus, although medical management may provide symptomatic improvement at first, early coronary angiography and revascularization should be strongly considered in anyone with Wellens syndrome because it usually predicts impending anterior myocardial infarction.

Wellens syndrome is characterized by two patterns of T-wave changes. In 75% of cases, T waves are deeply ( $\geq 5$  mm) and symmetrically inverted in leads  $V_2$  through  $V_4$  (FIGURES 1E, 4B). In 25% of cases, the T wave has a characteristic positive-negative biphasic morphology in leads  $V_2$  through  $V_4$  (FIGURES 1D, 4A).<sup>10</sup> In both patterns, the ST segment is isoelectric or minimally elevated ( $< 1$  mm) with a straight or convex morphology, the down-slope of the T wave is sharp, and the QT interval is often prolonged. These abnormalities are characteristically seen hours to days after the ischemic chest pain resolves. In fact, the ischemic episode is usually associated with transient ST-segment elevation or depression that progresses to the T-wave abnormality after the pain subsides.<sup>11</sup>

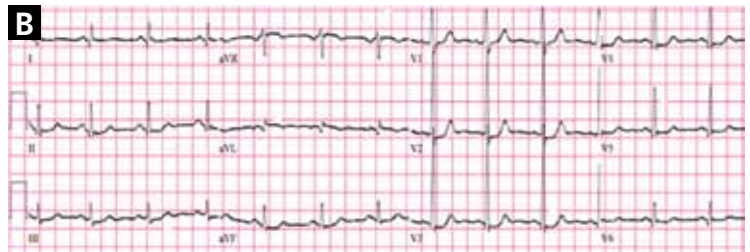
In Wellens' original description, only 12% of patients had increases in their creatine kinase levels, and these were small. Therefore, the electrocardiogram may be the only indication of an impending large anterior infarction in a chest-pain-free patient.<sup>12</sup>

T waves that are symmetrically but less deeply inverted than Wellens-type T waves may still represent ischemia. However, this finding is less specific for ischemia and is associated with better outcomes than Wellens syndrome or ST-segment deviation, particularly when the T wave is less than 3 mm deep.<sup>14</sup> In fact, one prospective cohort study found that isolated mild T-wave inversion in patients presenting with acute coronary syndrome is associated with a favorable long-term outcome, similar to that in patients with no electrocardiographic changes.<sup>15</sup>

## Posterior infarction



**FIGURE 5A.** ST-segment depression in the precordial leads  $V_1$ - $V_4r$  with a maximal depression in lead  $V_{3r}$  in a patient with severe ongoing chest pain for the preceding 3 hours. This suggests a posterior ST-segment elevation myocardial infarction. There is also a subtle ST-segment elevation in lead III, which further alludes to the diagnosis of infero-posterior infarction. Emergency coronary arteriography showed a totally occluded mid-left circumflex coronary artery.



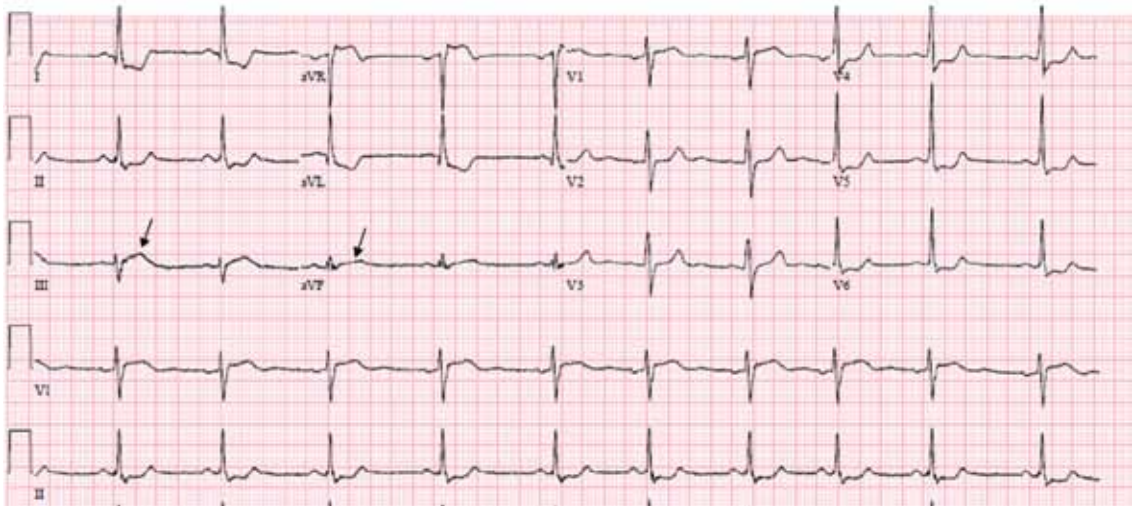
**FIGURE 5B.** The ST segment is depressed in leads  $V_1$  through  $V_6$  and leads II, III, and aVF, with a maximal depression in leads  $V_2$  and  $V_3$ . In addition, tall R waves are seen in leads  $V_1$  and  $V_2$  and Q waves are seen in the lateral leads I and aVL accompanied by ST elevation in aVL. In a patient with severe persistent chest pain, this suggests a posterolateral infarct. Coronary arteriography showed a totally occluded second obtuse marginal branch.

## FREQUENTLY MISSED DIAGNOSES MANIFESTING AS ST-SEGMENT DEPRESSION OR T-WAVE INVERSION

### True posterior ST-segment elevation myocardial infarction

When accompanied by inferior STEMI, posterior infarction is easily recognized, but it can be difficult to diagnose when it occurs alone, the so-called true posterior STEMI.

ST-segment depression that is most prominent in leads  $V_1$  through  $V_3$  often indicates posterior STEMI rather than non-ST-segment elevation ischemia and indicates the need for emergency revascularization. In fact, in the setting of posterior infarction, leads  $V_1$ ,  $V_2$ , and  $V_3$  predominate as the areas



**FIGURE 6.** Example of subtle ST-segment elevation in two contiguous leads with a prominent ST-segment depression in other leads. The ST segment is depressed in leads I and aVL and V<sub>4r</sub>, V<sub>5r</sub>, and V<sub>6r</sub>. There is a subtle ST-segment elevation with a broad hyperacute T wave in leads III and aVF fused with the ST segment in a convex fashion (arrows), suggesting that the primary abnormality is actually an acute inferior injury. Coronary arteriography showed a totally occluded right coronary artery in its mid-segment and severe left circumflex disease. The ST-segment depression is partly reciprocal to the inferior injury and partly a reflection of left circumflex-related ischemia.

of maximum depression, whereas greater ST-segment depression in the lateral precordial leads (V<sub>4</sub>, V<sub>5</sub>, and V<sub>6</sub>) or inferior leads (II, III, and aVF) is more indicative of nonocclusive and nonregional subendocardial ischemia (FIGURE 5).<sup>8,16–18</sup>

In most cases of posterior infarction, the posterior chest leads V<sub>7</sub>, V<sub>8</sub>, and V<sub>9</sub> reveal ST-segment elevation.<sup>19</sup> One study found that ST-segment depression in the anterior precordial leads was as sensitive as ST-segment elevation in leads V<sub>7</sub> through V<sub>9</sub> in identifying posterior myocardial infarction (sensitivity 80%),<sup>20</sup> while other studies found that ST-segment deviation on standard 12-lead electrocardiography has a lower sensitivity (about 60%) in identifying posterior infarction.<sup>18,21</sup>

Tall or wide ( $\geq 0.04$ -s) R waves in leads V<sub>1</sub> or V<sub>2</sub>, particularly when associated with upright T waves, suggest posterior infarction and may further corroborate this diagnosis, but this finding may take up to 24 hours to manifest and is seen in only about 50% of patients with posterior infarction.<sup>21</sup>

Studies have shown that ST-segment elevation on standard 12-lead electrocardiography is found in fewer than 50% of patients with acute left circumflex occlusion and in-

feroposterior infarction,<sup>18</sup> yet these are cases of “missed” STEMI that indeed benefit from emergency angiography and reperfusion. In addition, studies of non-ST-segment elevation acute coronary syndrome consistently identify patients who have epicardial vessel occlusion (about 15%–20% of cases),<sup>18</sup> yet their initial angiography is usually delayed for hours or days after the initial presentation.

A subgroup analysis from TRITON-TIMI 38 (Trial to Assess Improvement in Therapeutic Outcomes by Optimizing Platelet Inhibition With Prasugrel Thrombolysis in Myocardial Infarction 38) evaluated patients with isolated anterior ST-segment depression. An occluded “culprit” artery was found 26% of the time, most often the left circumflex artery. Moreover, those patients had a significantly higher rate of death or myocardial infarction at 30-day follow-up than patients without a culprit artery, probably related to delayed revascularization.<sup>22</sup>

Recognizing that ST-segment depression that is greatest in leads V<sub>1</sub>, V<sub>2</sub>, or V<sub>3</sub> represents posterior infarction helps identify a portion of the missed STEMIs in a timely fashion. In addition, in cases of anterior ST-segment depression and in cases of chest pain with nondiagnostic electrocardiography, the recording of



ST elevation in leads  $V_7$ ,  $V_8$ , and  $V_9$  is highly sensitive for detecting a true posterior injury.

### Acute pulmonary embolism

An anterior ischemic pattern of symmetric T-wave inversion in the precordial leads  $V_1$  through  $V_4$  may also be a sign of acute or chronic right ventricular strain, particularly acute pulmonary embolism. Sinus tachycardia is usually present, but other signs of pulmonary embolism, such as right ventricular hypertrophy and right bundle branch block, may be absent. In fact, T-wave inversion in leads  $V_1$  through  $V_4$  is noted in 19% of patients with nonmassive pulmonary embolism and in 85% of patients with massive pulmonary embolism, and is the most sensitive and specific electrocardiographic finding in massive pulmonary embolism.<sup>23</sup>

In addition, acute pulmonary embolism may be associated with T-wave inversion in leads III and aVF,<sup>24</sup> and changes of concomitant anterior and inferior ischemia should always raise the question of this diagnosis.

In one retrospective study of patients with acute pulmonary embolism, nonspecific ST-segment or T-wave changes were the most common finding on electrocardiography, noted in 49%.<sup>25</sup> Rapid regression of these changes on serial tracings favors pulmonary embolism rather than myocardial infarction.

### ST-segment depression reciprocal to a subtle ST-segment elevation

When ST-segment elevation occurs in two contiguous standard leads while ST-segment depression occurs in other leads, and when the ST-segment and T-wave abnormalities are ischemic rather than secondary to depolarization abnormalities, ST-segment elevation is considered the primary ischemic abnormality whereas ST-segment depression is often considered a reciprocal “mirror image” change. This “reciprocal” change may also represent remote ischemia in a distant territory in patients with multivessel coronary disease.<sup>26,27</sup>

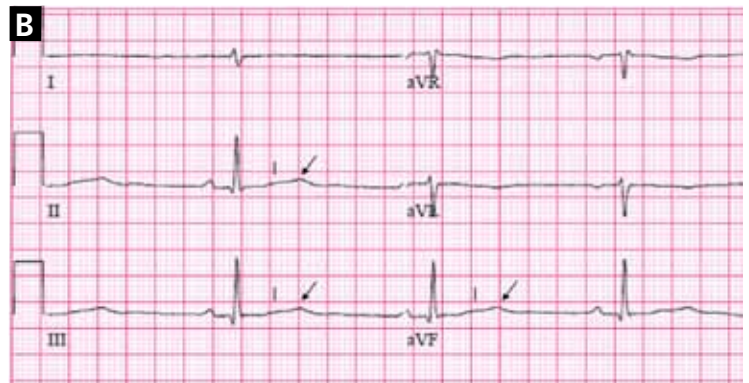
Reciprocal ST-segment depression is present in all patients with inferior myocardial infarction and in 70% of patients with anterior myocardial infarction.<sup>28</sup>

However, it is important to recognize that the magnitude of ST-segment elevation and reciprocal ST-segment depression is affected

## Hypokalemia



**FIGURE 7A.** Note the progressive flattening of the T wave, increase in U wave amplitude, and depression of the ST segment with progressive levels of hypokalemia (serum potassium levels are expressed in mEq/L).



**FIGURE 7B.** Electrocardiogram of a patient with a serum potassium level of 2.8 mEq/L. Note the flattened T waves (bars) and the prominent U waves (arrows).

## Global T-wave inversion

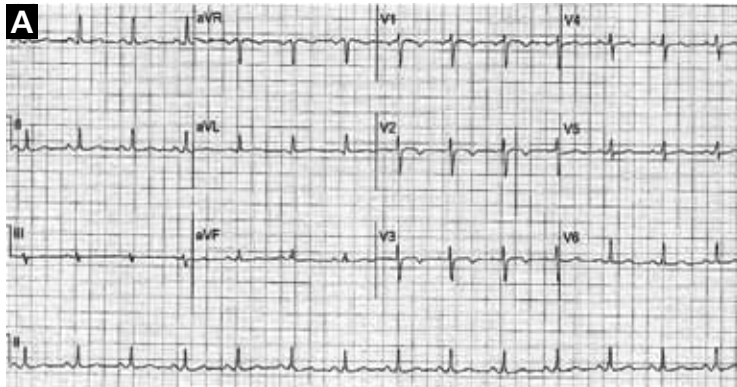


**FIGURE 8.** Global T-wave inversion with marked QT prolongation in a 77-year-old woman presenting with dyspnea and elevated cardiac biomarkers. Her coronary arteriography showed a 90% distal left main stenosis extending into the proximal left anterior descending and left circumflex coronary arteries.

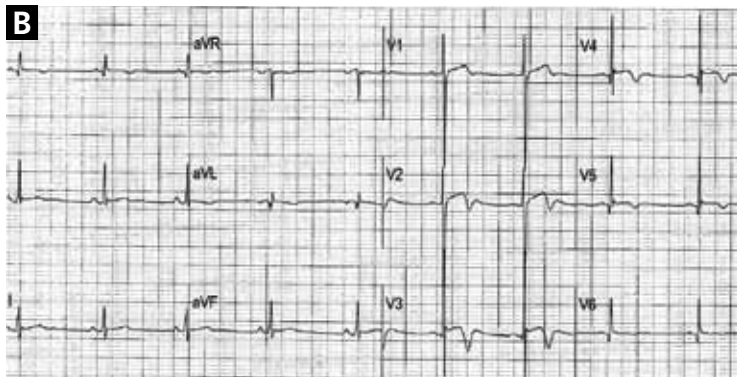
REPRODUCED WITH PERMISSION FROM GLANCY DL, ROCHON BJ, ILIE CC, PARKER JM, JONES MB, ATLURI P. GLOBAL T-WAVE INVERSION IN A 77-YEAR-OLD WOMAN. PROC (BAYL UNIV MED CENT) 2009; 22:81–82.



### Normal variants of repolarization



**FIGURE 9A.** Persistent juvenile T-wave pattern in a 40-year-old woman with T-wave inversion extending from lead V<sub>1</sub> to lead V<sub>4</sub>. The depth of the inverted T waves decreases between V<sub>1</sub> and V<sub>4</sub>. Also, the T wave progressively becomes less deeply inverted as the patient ages.



**FIGURE 9B.** Normal variant terminal T-wave inversion with ST-segment elevation in leads V<sub>2</sub> through V<sub>5</sub> in a 21-year-old black man. This pattern is most often seen in young black men, a few of whom at other times manifest the typical early repolarization pattern. The age and clinical presentation distinguish this pattern from Wellens-type T waves.

by the distance of the leads recording these changes from the ischemic region and their angle of deviation from the ischemic region.<sup>29</sup> This explains why occasionally—and particularly when the overall amplitude of the QRS complex is low—the magnitude of ST-segment elevation is small, whereas the reciprocal ST-segment depression is more prominent. In fact, in the absence of left ventricular hypertrophy or left bundle branch block, the reciprocal ST-segment depression should be sought. It is of great utility in patients with acute cardiac symptoms and mild elevation of ST segments of 1 to 1.5 mm in two contigu-

ous leads, as it strongly suggests the diagnosis of STEMI rather than other causes of mild ST-segment elevation (1–1.5 mm) (FIGURE 6).<sup>30</sup> The less-pronounced ST-segment elevation is often overlooked, and the patient is erroneously diagnosed with non-ST-segment elevation acute coronary syndrome rather than STEMI. This has a marked impact on patient management, as STEMI requires emergency revascularization, while non-ST-segment elevation ischemia requires early (but not emergency) coronary angiography.

### Hypokalemia and digitalis effect

ST-segment depression, T-wave flattening, and prominent U waves are the hallmarks of hypokalemia and can be mistaken for ischemic changes, including ischemic lengthening of the QT interval (FIGURE 7).<sup>31–34</sup> Digitalis also produces ST-segment depression, low or inverted T waves, and prominent U waves, but the U waves rarely are of the giant variety seen with severe hypokalemia, and the ST-segment depression has a sagging shape. In addition, digitalis shortens the QT interval.

### ■ DIFFUSE (GLOBAL) T-WAVE INVERSION

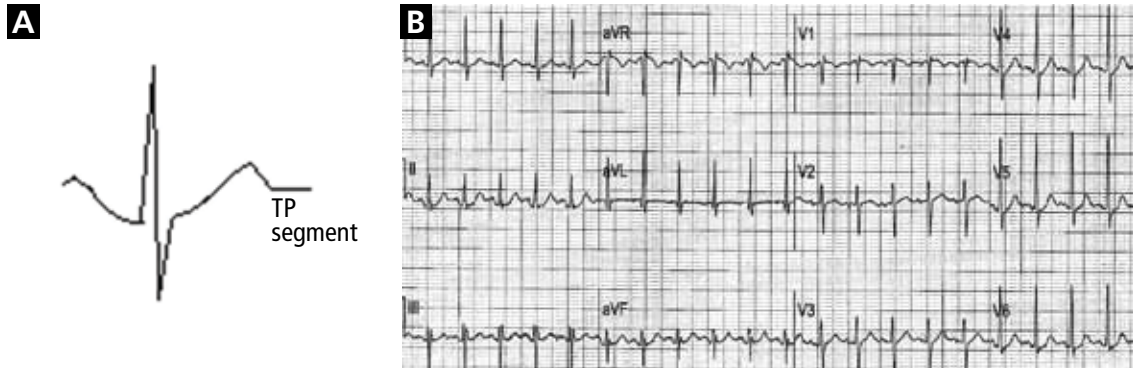
This term is applied when the T wave is inverted in most of the standard leads except aVR, which shows a reciprocal upright T wave. The QT interval is often prolonged, and T-wave inversion is often symmetric and “giant” (> 10 mm) (FIGURE 8).<sup>1,35</sup>

Walder and Spodick<sup>36</sup> have found this pattern to be caused most often by myocardial ischemia or neurologic events, particularly intracranial hemorrhage, and it seems more prevalent in women. Other causes include hypertrophic cardiomyopathy, stress-induced cardiomyopathy (takotsubo cardiomyopathy), cocaine abuse, pericarditis, pulmonary embolism, and advanced or complete atrioventricular block.<sup>36,37</sup>

The prognosis in patients with global T-wave inversion is determined by the underlying disease, and the striking T-wave changes per se do not imply a poor prognosis.<sup>38</sup>

Of note, takotsubo cardiomyopathy is characterized by electrocardiographic changes that mimic ischemia, especially

## Sinus tachycardia



**FIGURE 10.** (A) Up-sloping ST-segment depression in a case of sinus tachycardia. This is related to the exaggerated atrial repolarization that occurs during tachycardia and depresses the PR segment and the initial portion of the ST-segment when compared with the TP segment.

(B) Electrocardiogram of a patient with sinus tachycardia and junctional ST-segment depression in leads II and V<sub>4</sub> through V<sub>6</sub>. It has no pathologic significance.

STEMI, and is often impossible to differentiate from myocardial ischemia related to a coronary event without performing coronary arteriography. The most common abnormality on the admission electrocardiogram is ST-segment elevation (present in 46%–100% of patients), typically seen in the precordial leads. Within 48 hours of presentation, almost all patients also develop postischemic diffuse T-wave inversion and prolongation of the QT interval. New Q waves may be seen in 6% to 31% of pa-

tients and are usually transient.<sup>39,40</sup>

### OTHER CAUSES OF T-WAVE INVERSION OR ST-SEGMENT DEPRESSION

Various other entities may cause T-wave inversion, notably acute pericarditis or myocarditis,<sup>41,42</sup> memory T-wave phenomenon,<sup>43,44</sup> and normal variants of repolarization (TABLE 1, FIGURE 9).<sup>45</sup> Additionally, a nonpathologic junctional ST-segment depression may be seen in tachycardia (FIGURE 10).

### REFERENCES

- Rautaharju PM, Surawicz B, Gettes LS, et al; American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; American College of Cardiology Foundation; Heart Rhythm Society. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part IV: the ST segment, T and U waves, and the QT interval: a scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society. Endorsed by the International Society for Computerized Electrocardiology. *J Am Coll Cardiol* 2009; 53:982–991.
- Surawicz B, Knilans TK. Non-Q wave myocardial infarction, unstable angina pectoris, myocardial ischemia. In: Chou's *Electrocardiography in Clinical Practice: Adult and Pediatric*. 5th ed. Philadelphia: WB Saunders; 2001:194–207.
- Antman EM, Anbe DT, Armstrong PW, et al. ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction; A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Revise the 1999 Guidelines for the Management of patients with acute myocardial infarction). *J Am Coll Cardiol* 2004; 44:E1–E211.
- Okin PM, Devereux RB, Nieminen MS, et al; LIFE Study Investigators. Electrocardiographic strain pattern and prediction of new-onset congestive heart failure in hypertensive patients: the Losartan Intervention for Endpoint Reduction in Hypertension (LIFE) study. *Circulation* 2006; 113:67–73.
- Huwez FU, Pringle SD, Macfarlane PW. Variable patterns of ST-T abnormalities in patients with left ventricular hypertrophy and normal coronary arteries. *Br Heart J* 1992; 67:304–307.
- Li D, Li CY, Yong AC, Kilpatrick D. Source of electrocardiographic ST changes in subendocardial ischemia. *Circ Res* 1998; 82:957–970.
- Gorgels AP, Vos MA, Mulleneers R, de Zwaan C, Bär FW, Wellens HJ. Value of the electrocardiogram in diagnosing the number of severely narrowed coronary arteries in rest angina pectoris. *Am J Cardiol* 1993; 72:999–1003.
- Glancy DL. Electrocardiographic diagnosis of acute myocardial infarction. *J La State Med Soc* 2002; 154:66–75.
- Yamaji H, Iwasaki K, Kusachi S, et al. Prediction of acute left main coronary artery obstruction by 12-lead electrocardiography. ST segment elevation in lead aVR with less ST segment elevation in lead V(1). *J Am Coll Cardiol* 2001; 38:1348–1354.
- de Zwaan C, Bär FW, Wellens HJ. Characteristic electrocardiographic pattern indicating a critical stenosis high in left anterior descending coronary artery in patients admitted because of impending myocardial infarction. *Am Heart J* 1982; 103:730–736.
- de Zwaan C, Bär FW, Janssen JH, et al. Angiographic and clinical characteristics of patients with unstable angina showing an ECG pattern indicating critical narrowing of the proximal LAD coronary artery. *Am Heart J* 1989; 117:657–665.

12. Lilaonitkul M, Robinson K, Roberts M. Wellens' syndrome: significance of ECG pattern recognition in the emergency department. *Emerg Med J* 2009; 26:750-751.
13. Glancy DL, Khuri B, Cospolich B. Heed the warning: Wellens' type T-wave inversion is caused by proximal left anterior descending lesion. *Proc (Bayl Univ Med Cent)* 2000; 13:416-418.
14. Savonitto S, Ardissino D, Granger CB, et al. Prognostic value of the admission electrocardiogram in acute coronary syndromes. *JAMA* 1999; 281:707-713.
15. Mueller C, Neumann FJ, Perach W, Perruchoud AP, Buettner HJ. Prognostic value of the admission electrocardiogram in patients with unstable angina/non-ST-segment elevation myocardial infarction treated with very early revascularization. *Am J Med* 2004; 117:145-150.
16. Boden WE, Spodick DH. Diagnostic significance of precordial ST-segment depression. *Am J Cardiol* 1989; 63:358-361.
17. Shah A, Wagner GS, Green CL, et al. Electrocardiographic differentiation of the ST-segment depression of acute myocardial injury due to the left circumflex artery occlusion from that of myocardial ischemia of nonocclusive etiologies. *Am J Cardiol* 1997; 80:512-513.
18. Krishnaswamy A, Lincoff AM, Menon V. Magnitude and consequences of missing the acute infarct-related circumflex artery. *Am Heart J* 2009; 158:706-712.
19. Matetzky S, Freimark D, Feinberg MS, et al. Acute myocardial infarction with isolated ST-segment elevation in posterior chest leads V7-9: "hidden" ST-segment elevations revealing acute posterior infarction. *J Am Coll Cardiol* 1999; 34:748-753.
20. Matetzky S, Freimark D, Chouraqui P, et al. Significance of ST segment elevations in posterior chest leads (V7 to V9) in patients with acute inferior myocardial infarction: application for thrombolytic therapy. *J Am Coll Cardiol* 1998; 31:506-511.
21. Huey BL, Beller GA, Kaiser DL, Gibson RS. A comprehensive analysis of myocardial infarction due to left circumflex artery occlusion: comparison with infarction due to right coronary artery and left anterior descending artery occlusion. *J Am Coll Cardiol* 1988; 12:1156-1166.
22. Gibson CM, Pride YB, Mohanavelu S, Wiviott SD, Antman EM, Braunwald E. Abstract 1999: Angiographic and clinical outcomes among patients with acute coronary syndrome presenting with isolated anterior ST-segment depressions. *Circulation* 2008; 118:S-654.
23. Ferrari E, Imbert A, Chevalier T, Mihoubi A, Morand P, Baudouy M. The ECG in pulmonary embolism. Predictive value of negative T waves in precordial leads—80 case reports. *Chest* 1997; 111:537-543.
24. Sreeram N, Cheriex EC, Smeets JL, Gorgels AP, Wellens HJ. Value of the 12-lead electrocardiogram at hospital admission in the diagnosis of pulmonary embolism. *Am J Cardiol* 1994; 73:298-303.
25. Stein PD, Terrin ML, Hales CA, et al. Clinical, laboratory, roentgenographic, and electrocardiographic findings in patients with acute pulmonary embolism and no pre-existing cardiac or pulmonary disease. *Chest* 1991; 100:598-603.
26. Norell MS, Lyons JP, Gardener JE, Layton CA, Balcon R. Significance of "reciprocal" ST segment depression: left ventriculographic observations during left anterior descending coronary angioplasty. *J Am Coll Cardiol* 1989; 13:1270-1274.
27. Haraphongse M, Tanomsup S, Jugdutt BI. Inferior ST segment depression during acute anterior myocardial infarction: clinical and angiographic correlations. *J Am Coll Cardiol* 1984; 4:467-476.
28. Surawicz B, Knilians TK. Acute ischemia: electrocardiographic patterns. In: *Chou's Electrocardiography in Clinical Practice: Adult and Pediatric*. 5th edition. Philadelphia: WB Saunders; 2001:122-153.
29. Wagner GS, Macfarlane P, Wellens H, et al; American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; American College of Cardiology Foundation; Heart Rhythm Society. AHA/ACCF/HRS recommendations for the standardization and interpretation of the electrocardiogram: part VI: acute ischemia/infarction: a scientific statement from the American Heart Association Electrocardiography and Arrhythmias Committee, Council on Clinical Cardiology; the American College of Cardiology Foundation; and the Heart Rhythm Society. Endorsed by the International Society for Computerized Electrocardiology. *J Am Coll Cardiol* 2009; 53:1003-1011.
30. Brady WJ, Perron AD, Syverud SA, et al. Reciprocal ST segment depression: impact on the electrocardiographic diagnosis of ST segment elevation acute myocardial infarction. *Am J Emerg Med* 2002; 20:35-38.
31. Surawicz B. Electrolytes and the electrocardiogram. *Postgrad Med* 1974; 55:123-129.
32. Diercks DB, Shumaik GM, Harrigan RA, Brady WJ, Chan TC. Electrocardiographic manifestations: electrolyte abnormalities. *J Emerg Med* 2004; 27:153-160.
33. Glancy DL, Wang WL. ECG of the month. Abnormal electrocardiogram in a woman with a urinary tract infection. Sinus rhythm, rate 82/minute. Sagging ST segments, low T waves, and prominent U waves suggest hypokalemia. *J La State Med Soc* 2007; 159:5-7.
34. Surawicz B, Braun HA, Crum WB, Kemp RL, Wagner S, Bellet S. Quantitative analysis of the electrocardiographic pattern of hypokalemia. *Circulation* 1957; 16:750-763.
35. Glancy DL, Rochon BJ, Ilie CC, Parker JM, Jones MB, Atluri P. Global T-wave inversion in a 77-year-old woman. *Proc (Bayl Univ Med Cent)* 2009; 22:81-82.
36. Walder LA, Spodick DH. Global T wave inversion. *J Am Coll Cardiol* 1991; 17:1479-1485.
37. Lui CY. Acute pulmonary embolism as the cause of global T wave inversion and QT prolongation. A case report. *J Electrocardiol* 1993; 26:91-95.
38. Walder LA, Spodick DH. Global T wave inversion: long-term follow-up. *J Am Coll Cardiol* 1993; 21:1652-1656.
39. Bybee KA, Kara T, Prasad A, et al. Systematic review: transient left ventricular apical ballooning: a syndrome that mimics ST-segment elevation myocardial infarction. *Ann Intern Med* 2004; 141:858-865.
40. Wittstein IS, Thiemann DR, Lima JA, et al. Neurohumoral features of myocardial stunning due to sudden emotional stress. *N Engl J Med* 2005; 352:539-548.
41. Spodick DH. Electrocardiogram in acute pericarditis. Distributions of morphologic and axial changes by stages. *Am J Cardiol* 1974; 33:470-474.
42. Magnani JW, Dec GW. Myocarditis: current trends in diagnosis and treatment. *Circulation* 2006; 113:876-890.
43. Rosenbaum MB, Blanco HH, Elizari MV, Lazzari JO, Davidenko JM. Electrotonic modulation of the T wave and cardiac memory. *Am J Cardiol* 1982; 50:213-222.
44. Paparella N, Ouyang F, Fuca G, Kuck KH, Cappato R, Alboni P. Significance of newly acquired negative T waves after interruption of paroxysmal reentrant supraventricular tachycardia with narrow QRS complex. *Am J Cardiol* 2000; 85:261-263.
45. Kaid KA, Maqsood A, Cohen M, Rothfeld E. Further characterization of the "persistent juvenile T-wave pattern" in adults. *J Electrocardiol* 2008; 41:644-645.

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